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Comparative Analysis of Three Geodetic Datum Transformation Software for Application between WGS84 and Minna Datums

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Abstract
Since positions are computed on the local ellipsoids adopted for geodetic computation in various countries and as some of the geographic positions of the reference/control stations in Nigeria were determined on the WGS 84 ellipsoid, this paper has comparatively analyzed three geodetic datum transformation software with a view to determining which of them is most suitable for transformation between WGS 84 and Minna datums. The positions of five points obtained from the processing of GNSS observations using Compass post processing software were used. The WGS 84 geographic coordinates were transformed and converted to rectangular coordinates on the Minna datum using Columbus, AllTrans and GeoCalc software. The transformed and converted coordinates of the points were compared with the rectangular coordinates of the points obtained with Compass software to determine which of the software is most suitable for application between WGS 84 and Minna datums. The comparison results show that Columbus and AllTrans software are more suitable for transformation between WGS84 and Minna datums.

Keywords: Columbus, AllTrans, GeoCalc, Transformation software, Minna datum, Comparative Analysis

1 INTRODUCTION

World Geodetic System 1984, WGS 84 datum/ellipsoid is a global datum/ellipsoid that enables geodetic computations to be carried in any part of the world. This ellipsoid best fit the entire world/globe but not regions. Consequently, various regions/countries have established various local geodetic datums as well as adopted various ellipsoids for accurate geodetic computation in the regions/countries. In Nigeria, the positions as well as coordinates of some reference points/controls were determined in WGS 84 datum/ellipsoid. To use these stations as reference/base stations for relative or differential GPS/GNSS observations, their positions have to be transformed to positions on the local geodetic datum, Minna datum. To transform these global positions to local datum positions, geodetic datum transformation software such as Columbus, GeoCalc and AllTrans software among others are used. Geodetic datum transformation involves moving the coordinates of points determined on a particular ellipsoid say, WGS 84 to coordinates of the same points obtained with respect to another ellipsoid say, Clarke 1880 (Minna datum). The application of any of the stated geodetic datum transformation software requires the use of the seven datum transformation parameters which in turn requires the application of the Bursa-Wolf transformation model. Also, to obtain the coordinates of these points in a rectangular system, either the zone or the belt parameters have to be applied. Therefore, this paper comparatively analyses three geodetic datum transformation software with a view to determining which of them is most suitable for application between WGS 84 and Minna datums.

1.1 Columbus software

Columbus is a one, two, and three dimensional network adjustment, network pre-analysis and coordinate transformation software package which allows one to create, edit, solve and analyze Vertical, Geodetic, State Plane, UTM, Custom Projection and Local NEE (North, East and Elevation) surveys anywhere in the world (Columbus, 2009). Columbus accepts terrestrial and/or GPS (satellite) observations to define networks. Columbus is not just a network adjustment package; it is a complete toolkit which can be used for on-the-fly COGO computations, coordinate transformations, geoid modelling and computation of areas of selected polygons in a project.

According to Columbus (2009), to report coordinate results in different form, Columbus provides a powerful set of coordinate transformation tools to generate Geodetic, State Plane, UTM, Custom Projection, Earth Centred Earth Fixed Cartesian, or Local North, East and Elevation (NEE or NEU) positions. To transform geodetic positions from one datum to another, Columbus provides rigorous three, four and seven parameter least squares datum transformation capability. Columbus also includes an assortment of Geodetic, State Plane, UTM, Local NEE coordinate geometry (COGO) routines for ad-hoc computations, network loop closure and open-ended traverses.

1.2 GeoCalc Software

The GeoCalc Software is a geodetic software that: enables conversion of coordinate data files between most of the commonly-used mapping systems world-wide; uses seven-parameter transformations; has user-definable parameters allowing deployment anywhere in the world on almost any spheroid or mapping system; includes a large number of

predefined mapping systems and spheroids; includes Geodetic Datum of Australia; compares geodesy of the same point in two different mapping systems; displays the geographic, geocentric and projection coordinates of 3 dimensional points in any defined Mapping System; displays point scale factor and grid convergence.

1.3 AllTrans Software

According to George (2012), use the AllTrans application to perform coordinate transformations between various coordinate systems. As mentioned above, one can perform conversions between coordinates using different mathematical representations and geodetic systems. One can perform transformations between Gauß-Krüger coordinates, UTM coordinates, geographic coordinates and 3D-Cartesian coordinates. Manually input the data or import it to perform the transformation. With AllTrans software, 7-Parameter Datum Transformation and calculation of datum transformation parameters using identical points can be carried out.

1.4 WGS 84 Datum

WGS 84 is an Earth-centered, Earth-fixed terrestrial reference system and geodetic datum. It is based on a consistent set of constants and model parameters that describe the Earth's size, shape, and gravity and geomagnetic fields. WGS 84 is the standard U.S. Department of Defense definition of a global reference system for geospatial information and is the reference system for the Global Positioning System (GPS). It is compatible with the International Terrestrial Reference System (ITRS). ICAO (2002) gave the parameters of the WGS 84 datum/ellipsoid as: Semi-major axis, a = 6378137.000m, Angular velocity, ω = 7.292115 × 10^{-5} rad s^{-1}, Geocentric gravitational constant (Mass of the earth's atmosphere included) GM = 398 600.5 km^3 s^{-2}, Normalized second degree zonal harmonic coefficient of the gravitational potential, C2,0 = –484.16685 × 10-6 and Flattening (derived from C2,0) f = 1/298.257223563.

1.5 The Nigeria Geodetic Datum

According to Eteje *et al* (2018), the Nigeria Minna datum is a geodetic datum that is suitable for use in Nigeria-onshore and offshore. Minna datum references the Clarke 1880 (RGS) ellipsoid (Semi-major axis, a = 6378249.145m; Flattening, f = 1/293.465) and the Greenwich prime meridian. The datum origin is fundamental point: Minna base station L40. Latitude: 9°38'08.87"N, longitude: 6°30'58.76"E (of Greenwich). It is a geodetic datum for topographic mapping. It was defined by information from NIMA (Eteje *et al*, 2018). Uzodinma *et al* (2013) gave the orthometric height, *H* of station L40 as: 281.13m.

1.6 Transformation between WGS84 and Minna Datums

The accurate transformation of positions on the WGS84 ellipsoid to Minna Datum, Clarke 1880 ellipsoid requires the application of the seven datum transformation parameters. The application of the seven datum transformation parameters requires their combination with the Cartesian coordinates, X, Y and Z (Eteje *et al*, 2018). These parameters consist of an origin shift in three dimensions (T_X, T_Y, T_Z), a rotation about each coordinate axis (R_X, R_Y, R_Z) and a change in scale (SΔ) (Ono, 2009). The model (Bursa-Wolf model) required for the transformation of positions from WGS84 ellipsoid to Minna datum is given as (Wolf, 1963, Bursa, 1966, Featherstone and Vanicek, 1999, Hakan *et al*, 2002 and Ono, 2009):

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{Minna} = \begin{pmatrix} T_X \\ T_Y \\ T_Z \end{pmatrix} + (1+\Delta S)\begin{pmatrix} 1 & R_Z & -R_Y \\ -R_Z & 1 & R_X \\ R_Y & -R_X & 1 \end{pmatrix}\begin{pmatrix} X \\ Y \\ Z \end{pmatrix}_{WGS84} \quad (1)$$

To apply equation (1), the geographic coordinates of points on the WGS84 ellipsoid have to be converted to Cartesian rectangular coordinates on the WGS84 datum. The equations for the conversion of the geographic coordinates, latitude, φ, longitude, λ and ellipsoidal height, h to Cartesian coordinates, X, Y and Z as given by Okwuashi and Eyoh (2012) are respectively:

$$X = (v+h)\cos\varphi\cos\lambda \quad (2)$$

$$Y = (v+h)\cos\varphi\sin\lambda \quad (3)$$

$$Z = \left[v(1-e^2)+h\right]\sin\varphi \quad (4)$$

Where, *v* in equations (2) to (4) is the radius of curvature in the prime vertical given by Okwuashi and Eyoh (2012) as:

$$v = \frac{a}{(1-e^2\sin^2\varphi)^{1/2}} \quad (5)$$

Where, *a* is the semi-major axis while e^2 = eccentricity squared $= 2f - f^2$

To obtain the positions of the points on the local datum, the WGS84 Cartesian coordinates are converted to Cartesian coordinates on the Minna datum using equation (1). To obtain the geographic coordinates of the points on the local datum, the local datum Cartesian coordinates are converted to geographic coordinates on the Clarke 1880 ellipsoid using equations (6) to (8) (Janssen, 2009):

$$\varphi = \tan^{-1}\left[\frac{Z}{\sqrt{X^2+Y^2}}\left(1-e^2\left(\frac{v}{v+h}\right)\right)^{-1}\right] \quad (6)$$

$$\lambda = \tan^{-1}\left[\frac{Y}{X}\right] \quad (7)$$

$$h = \sqrt{X^2+Y^2}.\sec\varphi - v \quad (8)$$

Where, *v* = radius of curvature as given in equation (5).

To obtain the positions of the points in the local rectangular coordinate system, Nigeria Traverse Mercator (NTM), the local geographic coordinates of the points are used. The models for the conversion of the local geographic coordinates to local rectangular system coordinates are detailed in Eteje *et al* (2018). Equations (1) to (8) are used to develop programs which these datum transformation software use.

The transformation parameters from WGS 84 to Minna Datum as given by the Office of the Surveyor-General of the Federation, OSGOF, Okeke (2014) and Okeke *et al* (2017) are:

$$\left.\begin{array}{l} T_x = 93.809786m \pm 0.375857310m \\ T_y = 89.748672m \pm 0.375857310m \\ T_z = -118.83766m \pm 0.375857310m \\ R_x = 0.000010827829 \pm 0.0000010311322 \\ R_y = 0.0000018504213 \pm 0.0000015709539 \\ R_z = 0.0000021194542 \pm 0.0000013005997 \\ S = 0.99999393 \pm 0.0000010048219 \end{array}\right\} \quad (9)$$

The Nigeria West Belt parameters as given by Eteje *et al* (2018) are:

Latitude Origin: 4^{o} 00´ 00"
Longitude Origin: 4^{o} 30´ 00"
False Northing: 0mN
False Easting: 230738.266mE
Scale Factor: 0.99975

2 METHODOLOGY

2.1 Data Acquisition

The coordinates used in this study were those of five points observed with CHC900 dual frequency GNSS receivers. The points were observed with respect to a nearby control station (FGPEDY33) using differential/relative technique. The observations were processed with compass post processing software. The geographic coordinates of the points were processed on the WGS 84 ellipsoid/datum while the rectangular coordinates were processed on the Minna datum (Nigeria West Belt). The transformation parameters from WGS 84 to Minna datum given in equation (9) were used. The scale factor was subtracted from 1 before it was used. Table 1 shows the geographic coordinates (WGS 84 ellipsoid) and rectangular coordinates (Minna datum) of the points.

Table 1: Geographic and Rectangular Coordinates of the Points

STATION	WGS84		MINNA (CLARKE ELLIPSOID)	
	LATITUDE	LONGITUDE	NORTHING (m)	EASTING (m)
SEO01	6^{o} 16' 42.97323"	5^{o} 38' 12.00033"	251980.6255	356579.8098
SEO02	6^{o} 16' 36.54880"	5^{o} 38' 10.50577"	251783.1869	356534.3011
SEO03	6^{o} 16' 33.29440"	5^{o} 38' 11.79138"	251683.3076	356574.0325
SEO04	6^{o} 16' 28.62157"	5^{o} 38' 11.27213"	251539.7379	356558.3840
SEO05	6^{o} 16' 25.25660"	5^{o} 38' 10.59745"	251436.3314	356537.8708

2.2 Data Processing

The geographic coordinates of the points given in table 1 were transformed and converted to Minna datum rectangular positions using Columbus, AllTrans and GeoCalc software. The positions of the points were converted to coordinates in the Nigeria Traverse Mercator, NTM as well as the Nigeria west belt. The transformation parameters given in equation (9) were also used. The scale factor was again subtracted from 1 before it was used. Figures 1, 2 and 3 respectively show the transformation and conversion of the global geographic positions to Minna datum rectangular coordinates using Columbus, AllTrans and GeoCalc software.

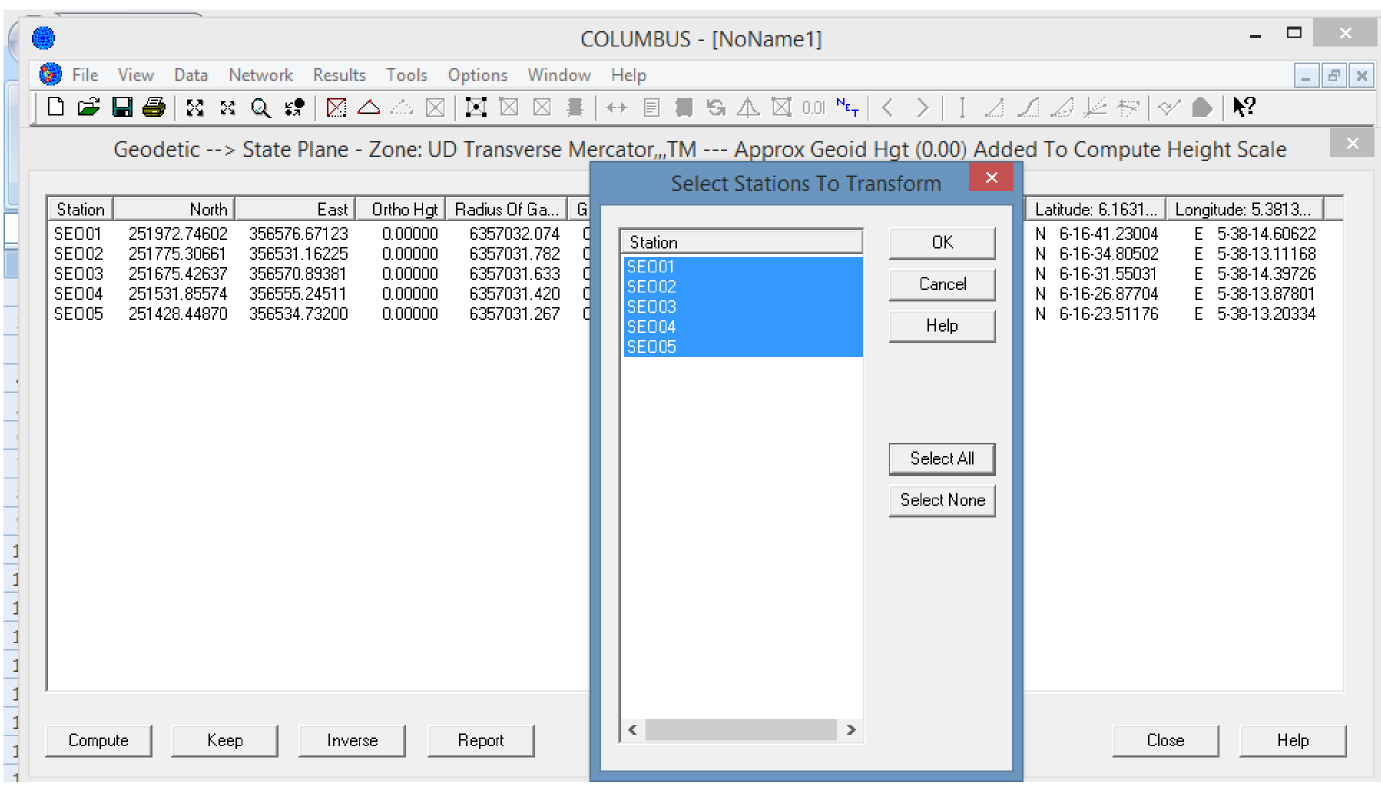

Fig. 1: Transformation and Conversion of the Global Geographic Positions to Minna Datum Rectangular Coordinates Using Columbus Software

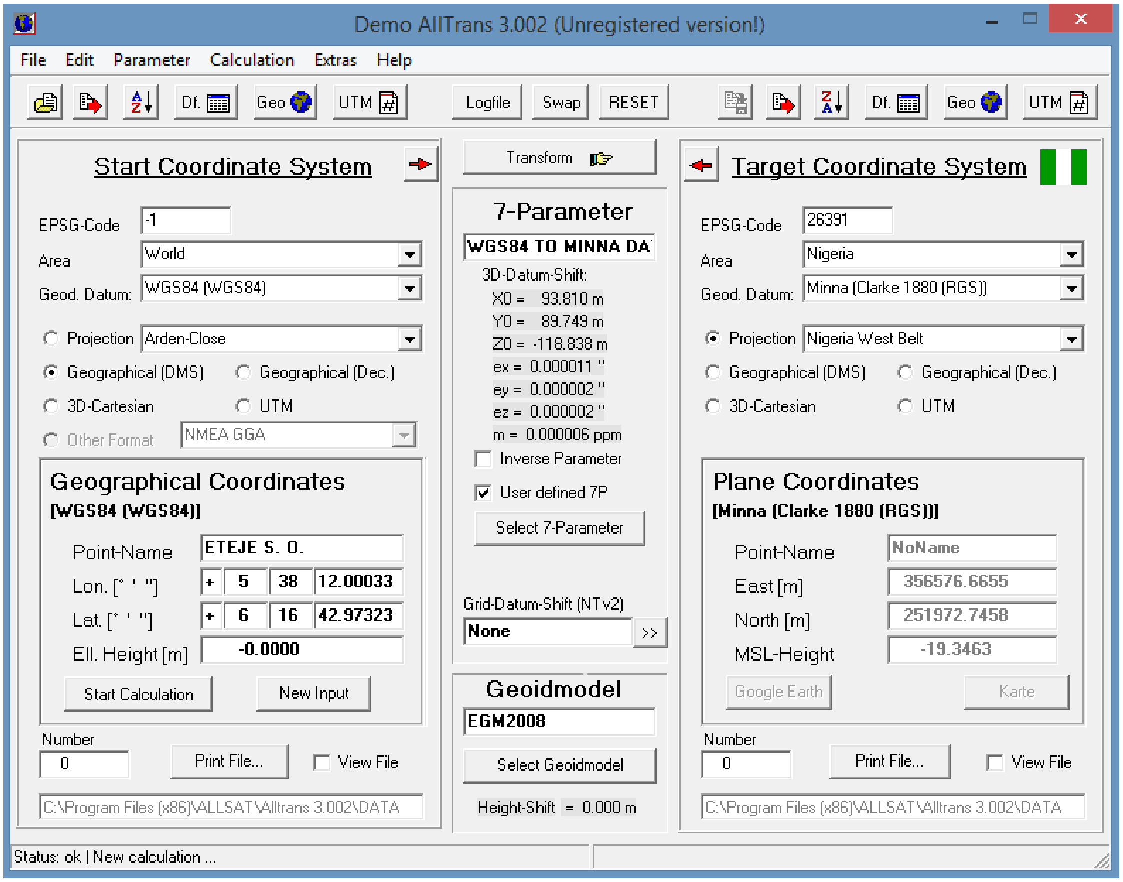

Fig. 2: Transformation and Conversion of the Global Geographic Positions to Minna Datum Rectangular Coordinates Using AllTrans Software

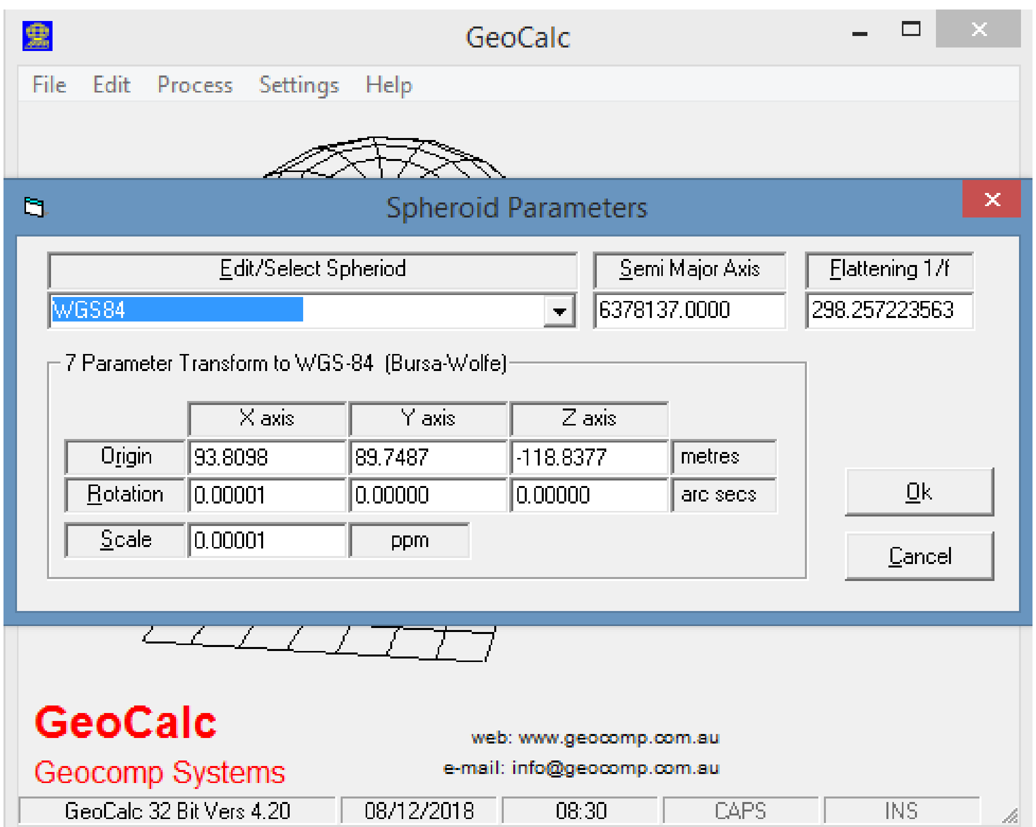

Fig. 3: Transformation and Conversion of the Global Geographic Positions to Minna Datum Rectangular Coordinates Using GeoCalc Software

2.3 Results Presentation and Analysis

Table 2 presents rectangular coordinates of the points obtained using Compass, Columbus, AllTrans and GeoCalc software. This was done to obtain the local rectangular coordinates of the points using the three transformation software. It can be seen from table 2 that the positions of the points obtained using Columbus and AllTrans software are in agreement. These two sets of positions of the points also agree more with the positions of the points obtained with the Compass software being the reference positions of the points than those obtained using GeoCalc software. This implies that Columbus and AllTrans software are more suitable for application between WGS 84 and Minna datums.

Table 2: Rectangular Coordinates of the Points Obtained Using Compass, Columbus, AllTrans and GeoCalc Software

STATION	MINNA (CLARKE ELLIPSOID)							
	COMPASS		COLUMBUS		GEOCAL		AllTrans	
	NORTHING (m)	EASTING (m)	NORTHING (m)	EASTING (m)	NORTHING (m)	EASTING (m)	NORTHING (m)	EASTING (m)
SEO01	251980.6255	356579.8098	251972.7460	356576.6712	251694.8359	356577.2335	251972.7458	356576.6655
SEO02	251783.1869	356534.3011	251775.3066	356531.1622	251497.3962	356531.7258	251775.3061	356531.1564
SEO03	251683.3076	356574.0325	251675.4264	356570.8938	251397.5156	356571.4573	251675.4260	356570.8881
SEO04	251539.7379	356558.3840	251531.8557	356555.2451	251253.9453	356555.8070	251531.8555	356555.2395
SEO05	251436.3314	356537.8708	251428.4487	356534.7320	251150.5368	356535.2960	251428.4484	356534.7263

Table 3 also presents the differences in positions between the coordinates of the points obtained using Compass software and those obtained with Columbus, AllTrans and GeoCalc software. This was done to obtain the amount with which the positions of the points obtained using the three datum transformation software differ from the reference positions of the points obtained using the Compass post processing software. It can be seen from table 3 that the maximum, minimum and mean differences in northing and easting with respect to Columbus, GeoCalc and AllTrans software are respectively 7.8827mN, 7.8795mN and 7.8812mN, 3.1389mE, 3.1386mE and 3.1388mE; 285.7946mN, 285.7896mN and 285.7919mN, 2.5770mE, 2.5748mE and 2.5757mE; and 7.8830mN, 7.8797mN and 7.8815mN, 3.1447mE, 3.1443mE and 3.1445mE. The differences in the coordinates/positions of the points were as a result of the errors in the global geographic coordinates of the points obtained during the GNSS observations processing using the Compass software. Since the GNSS observations were carried using relative technique, the coordinates of the points were constraint/adjusted with respect to those of the control station. Consequently, errors/offsets in northing and easting of 7.9016mN and 3.1438mE were respectively obtained (see figure 4).

Table 3: Points Coordinate Differences between Compass and the Datum Transformation Software

STATION	COLUMBUS		GEOCAL		AllTrans	
	DIFF. IN NORTHING (m)	DIFF. IN EASTING (m)	DIFF. IN NORTHING (m)	DIFF. IN EASTING (m)	DIFF. IN NORTHING (m)	DIFF. IN EASTING (m)
SEO01	7.8795	3.1386	285.7896	2.5763	7.8797	3.1443
SEO02	7.8803	3.1389	285.7907	2.5753	7.8808	3.1447
SEO03	7.8812	3.1387	285.7920	2.5752	7.8816	3.1444
SEO04	7.8822	3.1389	285.7926	2.5770	7.8824	3.1445
SEO05	7.8827	3.1388	285.7946	2.5748	7.8830	3.1445
MEAN DIFF =	**7.8812**	**3.1388**	**285.7919**	**2.5757**	**7.8815**	**3.1445**

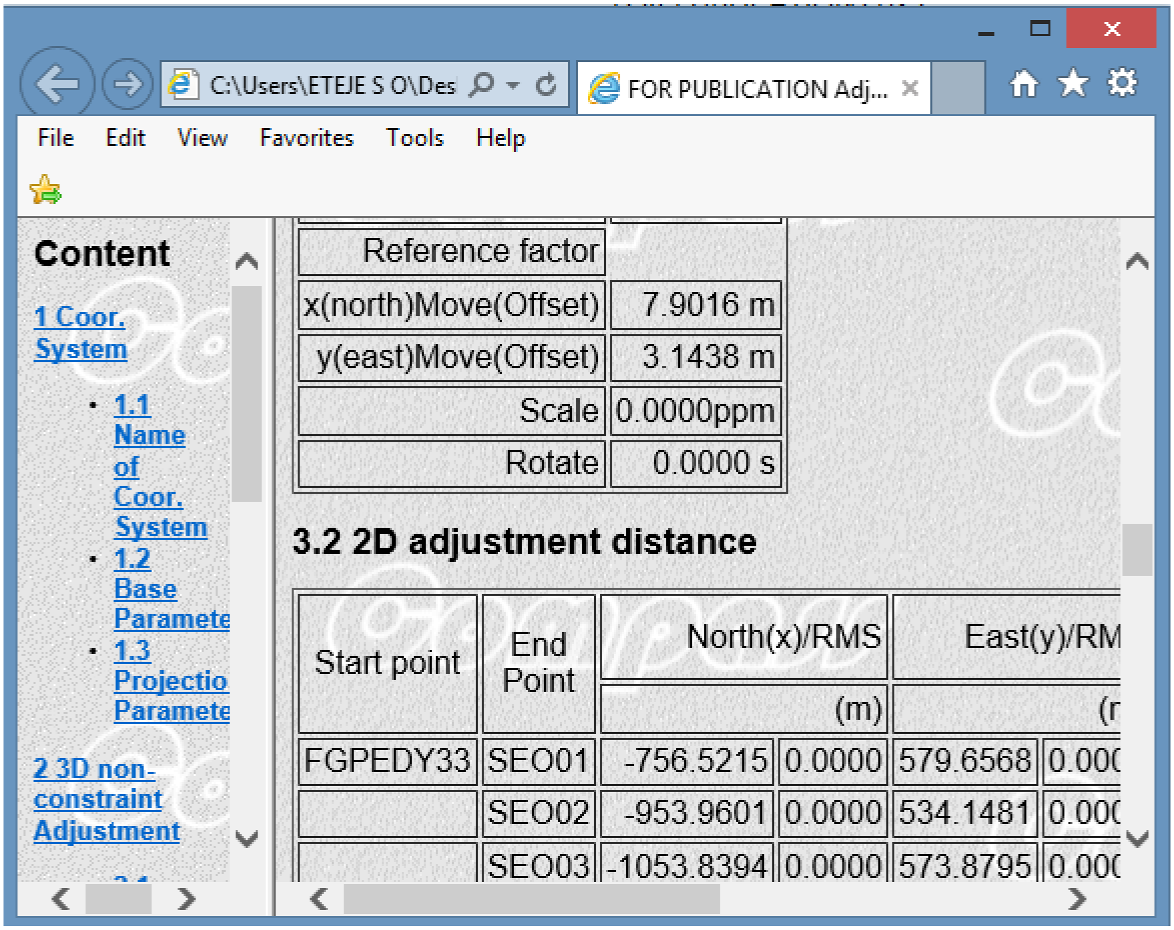

Fig. 4: Errors/Offsets in Northing and Easting of Compass Software Positions

Table 4 and figure 5 also present the differences between the offsets in the positions of the points obtained from the GNSS observations and the mean differences in coordinates. This was done to determine if the transformed positions of the points would agree with the coordinates of the points obtained using Compass software. Since the offsets were corrections added to the processed Compass software positions, subtracting the mean differences in the positions of the points from the offsets will give a better fit/agreement. It can be seen from table 4 and figure 5 that the differences between the offsets and the mean differences in positions of the points in northing and easting of Columbus and AllTrans software are respectively 0.0204mN, 0.0050mE and 0.0201mN, -0.0007mE while those of GeoCalc software are -277.8903mE, 0.5681mN which implies that Columbus and AllTrans software are more suitable for application between WGS 84 and Minna datums.

Table 4: Differences between Offsets and Mean Differences in Positions

SOFTWARE	**COLUMBUS**		**GEOCAL**		**AllTrans**	
COORDINATE	**NORTHING**	**EASTING**	**NORTHING**	**EASTING**	**NORTHING**	**EASTING**
OFFSET	7.9016	3.1438	7.9016	3.1438	7.9016	3.1438
MEAN DIFF	7.8812	3.1388	285.7919	2.5757	7.8815	3.1445
DIFFERENCE	0.0204	0.0050	-277.8903	0.5681	0.0201	-0.0007

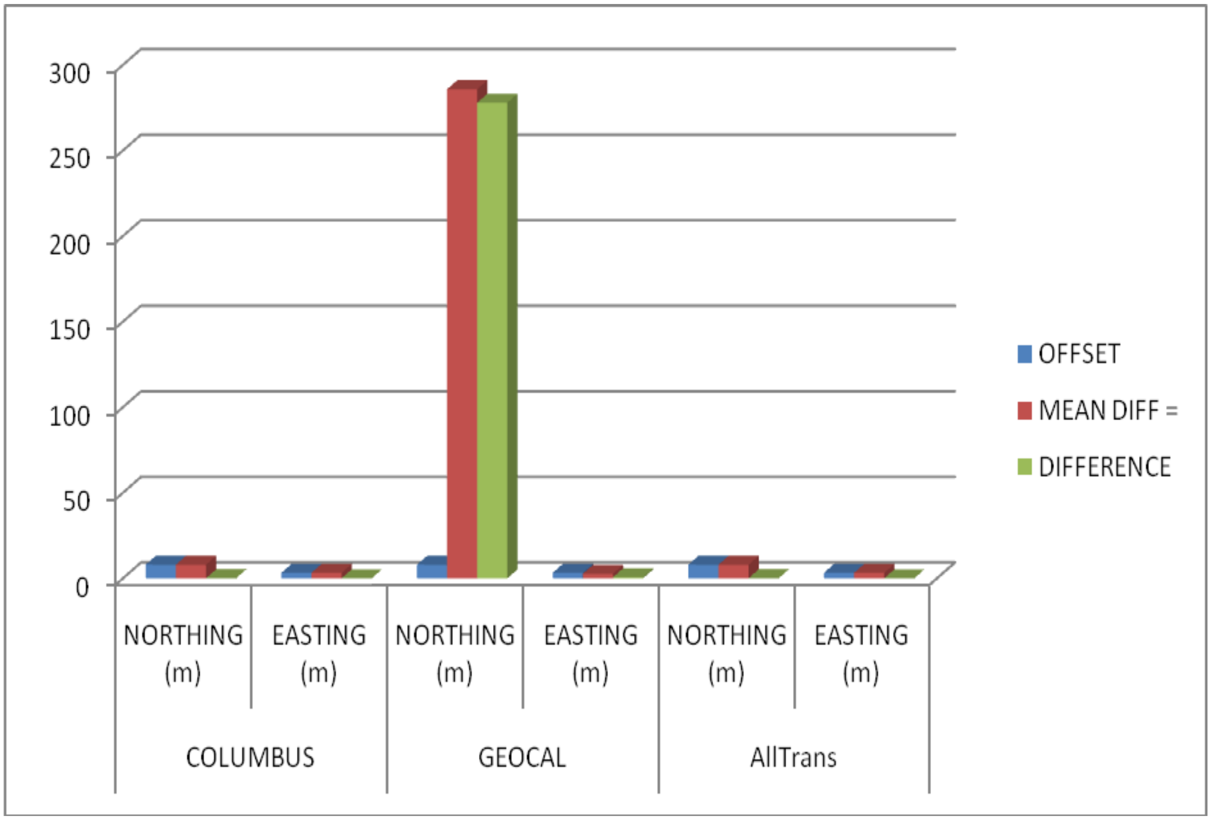

Figure 5: Plot of Differences between Compass Coordinates Offsets and Mean Differences in Positions

3 CONCLUSION

In Nigeria, the positions as well as coordinates of some reference points/control stations were determined in WGS84 datum/ellipsoid. To use these stations as reference/base stations for relative or differential GPS/GNSS observations, the global positions have to be transformed to positions on the local geodetic datum/ellipsoid, Minna datum. The transformation of the global positions to coordinates on the local datum involves the use of datum transformation software. Therefore, this paper has comparatively analyzed three datum transformation software (Columbus, AllTrans and GeoCalc) to determine which of them is most suitable for application between WGS 84 and Minna datums. The comparison results show that Columbus and AllTrans software are more suitable for transformation between WGS 84 and Minna datums.

REFERENCES

[1] Bursa, M. (1966): *Fundamentals of the Theory of Geometric Satellite Geodesy*. Travaux De l'institut Geophsique De l'academie Tehecoslovaque Des Sciences. In Hakan, S. K., Cetin, M. and Hakan, A. (2002): A Comparison of Two Well Known Models for 7-Parameter Transformation. *The Australian Surveyor* Vol. 47, No. 1, pp 24-30.

[2] Columbus (2009): *Columbus 3.8 User Manual.* Best Fit Computing Inc. 17490 NW Woodmere Court Beaverton, Oregon 97006 USA.

[3] Eteje S. O., Oduyebo O. F. and Olulade S. A. (2018): On the Determination of NTM and UTM Positions from Post Processing of Static DGPS Observations on the Nigeria Minna Datum. *International Journal of Engineering Research and Advanced Technology (IJERAT),* Vol. 4, No. 10.

[4] Eteje, S. O., Oduyebo, O. F. and Olulade, S. A. (2018): Comparison of the Positions Computed from DGPS/GNSS Observations Using the New/Unified and Various Old Transformation Parameters in Nigeria**.** *International Journal of Engineering Science and Computing (IJESC),* Vol. 8, No. 12, pp 19378-19385.

[5] Featherstone, W. and Vanicek, P. (1999): The Role of Coordinate Systems, Coordinates and Heights In Horizontal Datum Transformations. *The Australian Surveyor,* Vol. 44 No. 2. In Ono, M. N. (2009): On Problems of Coordinates, Coordinate Systems and Transformation Parameters in Local Map Production, Updates and Revisions in Nigeria. FIG Working Week, Eilat, Israel.

[6] George N. (2012): AllTrans - Geodetic 3D Transformations. http://alltrans.findmysoft.com. Accessed December 1st, 2018.

[7] Hakan, S. K., Cetin, M. and Hakan, A. (2002): A Comparison of Two Well Known Models for 7-Parameter Transformation. *The Australian Surveyor* Vol. 47, No. 1, pp 24-30

[8] ICAO (2002): World Geodetic System 1984 (WGS-84) Manual, Second Edition, International Civil Aviation Organization.

[9] Janssen, V. (2009): Understanding coordinate systems, datums and transformations in Australia. *International Journal of Geoinformatics*, Vol. 5, No. 4, pp. 41-53.

[10] Okeke, F. I. (2014): Assessment of the Capabilities of the National Transformation Version 2 (Ntv2) Model for the Nigerian Datum Transformation. National Union of Planetry and Radio Sciences (NUPRS) Conference.

[11] Okeke, F. I., Moka E. C., Uzodinma, V. N. and Ono, M. N. (2017): The Determination of Datum Transformation Parameters for Nigeria. *Nigerian Journal of Geodesy*, Vol. 1 No. 1 pp 49-64.

[12] Okwuashi, O, and Eyoh, A. (2012): 3D Coordinate Transformation Using Total Least Squares. *Academic Research International*, Vol. 3, No. 1, pp 399-405.

[13] Ono, M. N. (2009): On Problems of Coordinates, Coordinate Systems and Transformation Parameters in Local Map Production, Updates and Revisions in Nigeria. FIG Working Week, Eilat, Israel.

[14] Uzodinma, V. N., Oguntuase, J. O., Alohan, and Dimgba, C. N. (2013): *Practical GNSS Surveying*. Professor's Press Ltd, Enugu.

[15] Wolf, H. (1963): Geometric Connection and Re-Orientation of Three Dimensional Triangulation Nets. *Bulletin Geodesy*, Vol. 68, pp 165-169. In Hakan, S. K., Cetin, M. and Hakan, A. (2002): A Comparison of Two Well Known Models for 7-Parameter Transformation. *The Australian Surveyor*, Vol. 47, No. 1, pp 24-30.